A Smoke Detector Activation Algorithm for Fire Dynamics Simulator (FDS)

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Need for Smoke Detector Activation Model

- Early detection of fire plays an important role in the life safety of building occupants.
- Smoke detectors are commonly used devices to provide early warning.
- For purposes of:
  - Fire safety design
  - Fire reconstruction
  - Evaluation of detector performance

  it is essential to be able to predict with accuracy smoke detector activation times.

Smoke Detector Activation Models

- A number of fire analysis tools use a simplistic SD activation algorithm.
- Treats SD as a very sensitive thermal element (i.e. no thermal lag).
- Incorporates a weak correlation between temperature rise and smoke obscuration.
- Uses well-established plume and ceiling jet correlations coupled with a lumped-mass model for convective heat transfer to predict detector response.

Smoke Detector Activation Models

- Heskestad and Delichatsios, 1977.
  - 11.1°C temperature rise corresponds to detection.
  - Independent of fuel.
- There has been significant criticism, which has left substantial doubt as to its validity:
  - Beyler and DiNenno, 1991.
  - Schifiliti et al., 1996 and 2001.
  - Luck and Sievert, 1999.
  - Cholin and Marrion, 2001.
  - Mowrer and Friedman, 1998.
  - Gottuk et. al, 1999.
  - Wakelin, 1997.

Smoke Detector Activation Models

- Long been known – SD have an entry resistance to smoke.
- Smoke concentrations outside SD may reach threshold levels earlier than the smoke concentrations inside SD.
- Heskestad (1975) proposed a time lag correlation defined as a function of the free stream velocity.

Fire Dynamics Simulator (FDS)

- A SD activation algorithm will require the smoke density and 3-D flow field at a detector location as inputs.
- FDS has shown to effectively model fire and smoke transport in well-ventilated conditions, especially hen fire size is small compared to size of compartment when SD response is most relevant.
- Create a SD activation sub-model for FDS using smoke detector entry lag time correlations:
  - Heskestad, one parameter model
  - Cleary *et al.*, two parameter model

Heskestad Entry Lag Time Model

- **Assumes a lag time based on a characteristic length of the detector geometry:**

$$\Delta t_d = L/V$$

- **Theoretical way to deal with the resistances and passages connecting the outside of the detector housing to the sensing chamber:**
  - **Obtained experimentally.**
  - **Dependent on smoke velocity.**
    - **Adequate at high velocities.**
    - **Breaks down at low flow velocities.**

- **Relatively easy to obtain data experimentally.**

Cleary *et al.* Entry Lag Time Model

- **Two parameter model:**

  $$\delta t_e = \text{dwell time} = \alpha_e V^{-\beta_e}$$

  $$\delta t_c = \text{mixing time} = \alpha_c V^{-\beta_c}$$

- **The dwell time and characteristic mixing time are added in series.**

- **More complex than the Heskestad model.**

- **Shows good agreement at lower velocities in the range to which a smoke detector may be exposed to.**

Previous Work of D'Souza *et al.*

- Modeled small UL 217 heat sources in a room-corridor-room geometry instrumented with ionization smoke detectors.
- Assumed activation at approximately 7-17% obscuration per foot outside the detector (in line with UL 217 fire tests)
- Once 7% or 17% obscuration per foot was obtained at the detector, utilized the velocity at that time to determine lag time in accordance with Cleary *et al.*

Previous Work of D'Souza *et al.*

- Advantages:
  - Utilized smoke obscuration and velocity.
  - Showed good agreement with experimental data.
- Disadvantages:
  - Post-processing routine.
  - Does not calculate obscuration inside the sensing chamber.
  - Reported results as a range, which could be broad.

Heskestad Sub-Model

- **Can use the Heskestad correlation instead if you know the characteristic length, "L".**
- **Example values using Heskestad's approach:**

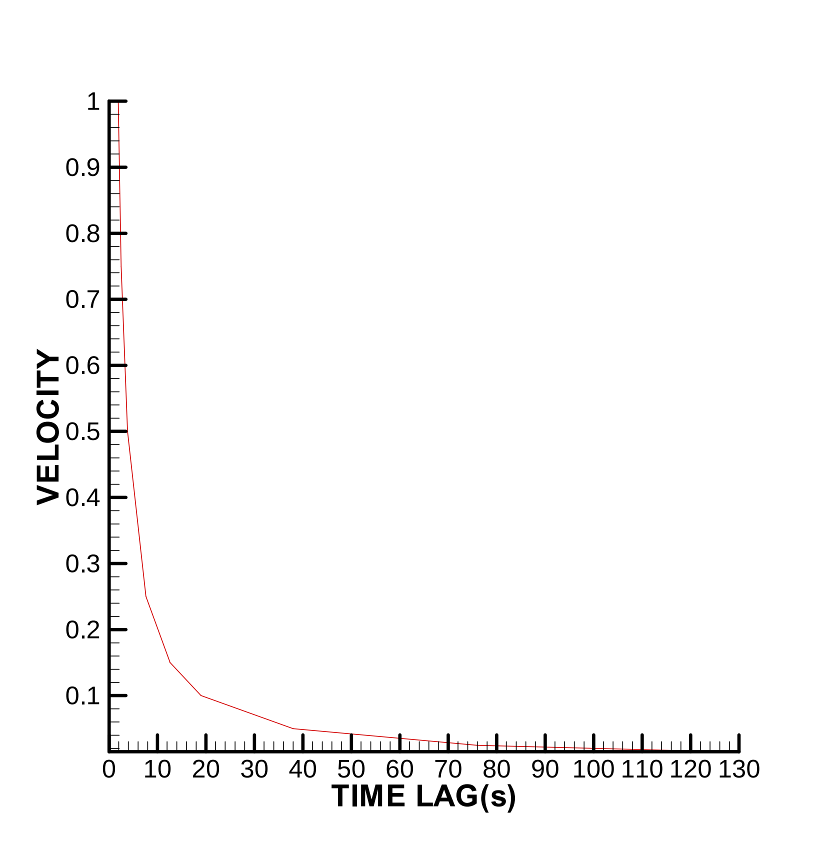
Detector	Alpha_E or L	Beta_E	Alpha_C	Beta_C
Heskestad	1.8	-1.0	0.0	-1.0

- **L/V correlation = to dwell time ($\delta t = \alpha V^{-\beta}$)**
- **Heskestad detector with reasonable characteristic L set as the default due to its ease of calculation (no need to calculate mixing time)**

Verification of Sub-Model

- **Modeled a wind tunnel with one of the "Cleary detectors".**

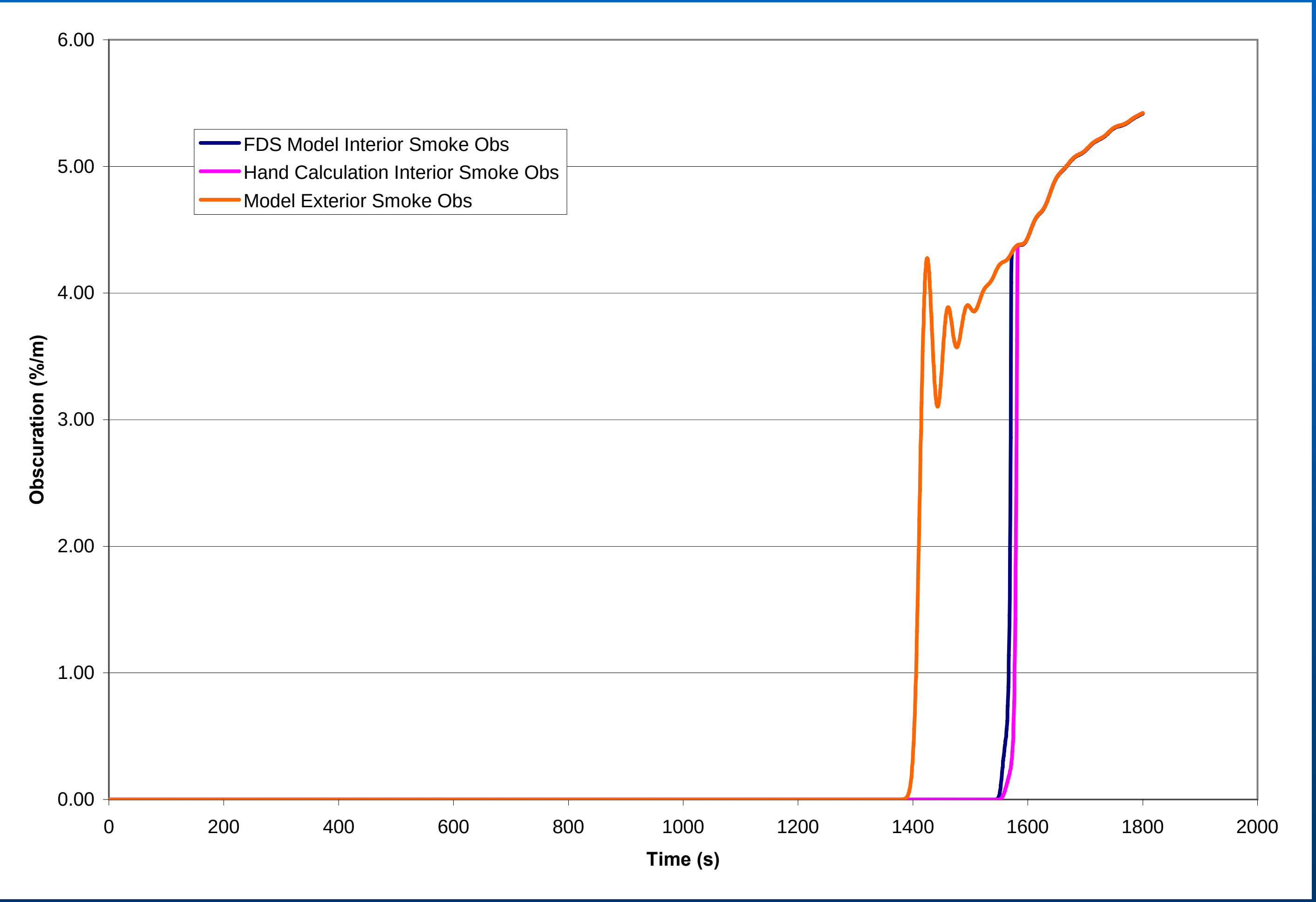
- **Critical entry velocity in literature of 0.15 m/s**



Above 0.15 m/s, the lag time is approximately 15s or less confirming the experimental results currently in the literature.

Verification of Sub-Model

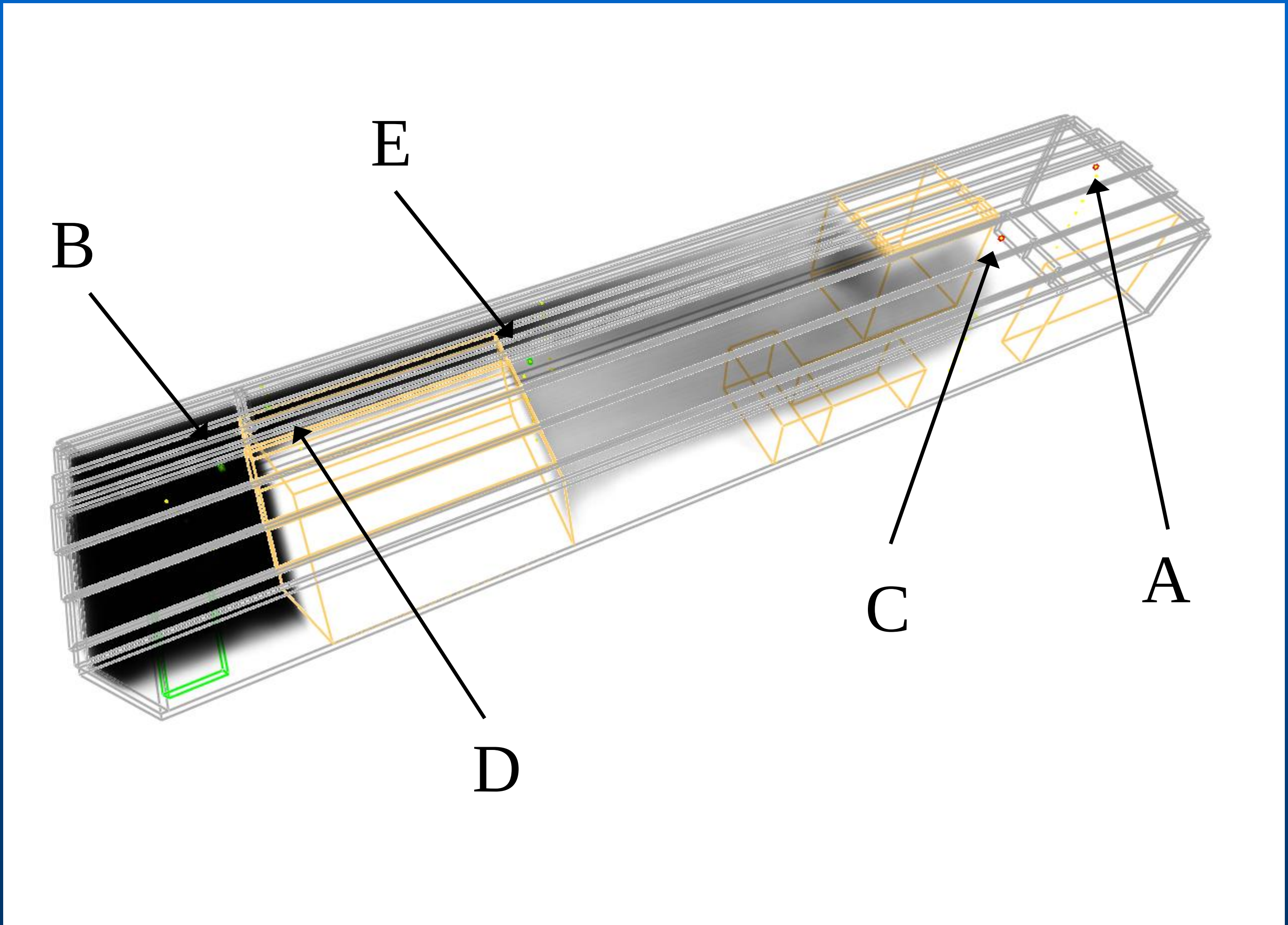
- Corridor model created in FDS.
- Allows for relatively slow velocity at the detector location.
- Heskestad detector with a characteristic Length L of 10.0 meters used to induce large entry lag time.
- Hand calculations compared with model results utilizing the velocity and smoke mass from the model.



Lag time approximately matches hand calculations

Validation: “Dunes 2000” Test 5

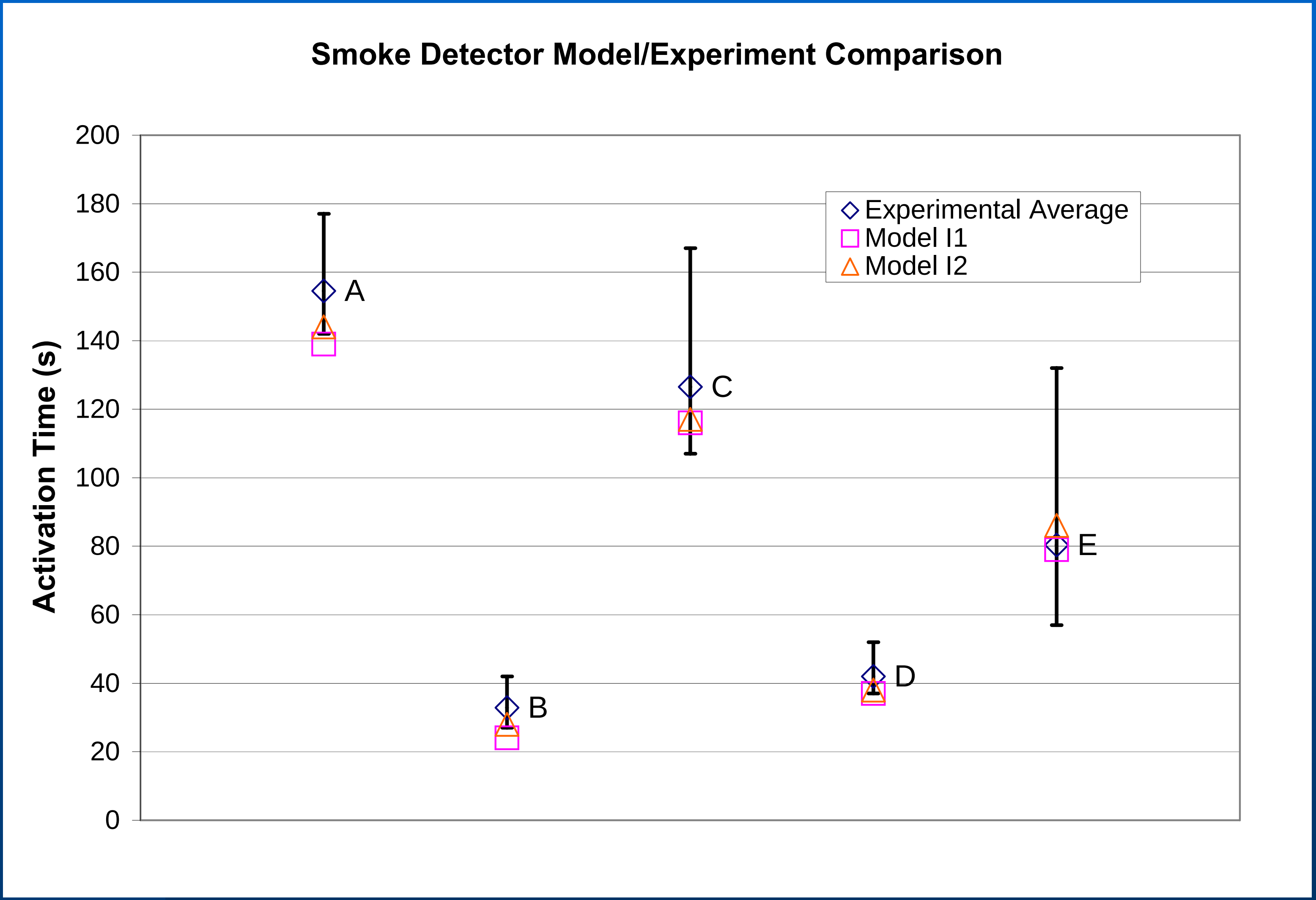
- Used data from “Dunes 2000” (Bukowski *et al.*) for comparison.
- Mattress fire in the bedroom of the manufactured home.
- Used mass loss data and heat of combustion to estimate HRR.



“Dunes 2000” Test 5 Results

SDC05	Room B- Main Bedroom (room of origin)	Room D – Hallway Outside Main Bedroom	Room E – Living room	Room C – Hallway Outside Remote Bedroom	Room A- Remote Bedroom
Experimental Range (s)	27 - 42	37 - 52	57 - 132	107 – 167	142 - 177
Experimental Average (s)	33	42	80	127	154
Model I1 (s)	24	37	79	116	139
Model I2 (s)	28	38	86	117	144
Maximum error (%)	27	12	8	9	10

Dunes 2000 Test 5 Results



"Dunes 2000" Test 5 Results

- Predicted the order of activation correctly.
- Often was in the range of activations from experimental data.
- Difference between experimental average and predicted times was less than 15% at all of the detector stations except the closest detector station.
- Error seemed to stabilize around 10% at detector stations further from the source.
- Error was in the direction of an under prediction. Not conservative to the designer.

Summary

- A robust smoke detector model has been integrated into FDS.
- Model can use a two parameter model (Cleary *et al.*) or a simplified one parameter model (Heskestad).
- Model results verify that it is correctly simulating the critical velocity described in the literature.
- Model results, when compared with hand-calculations, verifies that the algorithm is implemented correctly within FDS.
- Validation of smoke detector model can predict activation times within the range of activation times of the validation experiment, and within 15% of the average of those activation times.

Continuing Work

Verification:

- More robust "hand calculations".
- Development of a standard test case for future verification of new FDS releases.

Validation:

- More "Dunes 2000" comparisons, including 2-story home.
- NRC Canada testing.
- Develop separate appendix for documentation of validation.

The End

Questions?